A field mill for measuring atmospheric electricity

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Introduction

Every time we walk outside, we are bathed in force fields that are produced by nature. They are gravitational, magnetic and electric fields.

In the on-line text *Motion Mountain* – Volume 3, on page 209 – Christopher Schiller makes the following statement about electric fields:

"…every person should know that there is a vertical electric field of between 100 and 300 V/m on a clear day, as discovered in 1752; the earth is permanently negatively charged and, on a clear day, current flows downwards (electrons flow upwards) trying to discharge our planet."

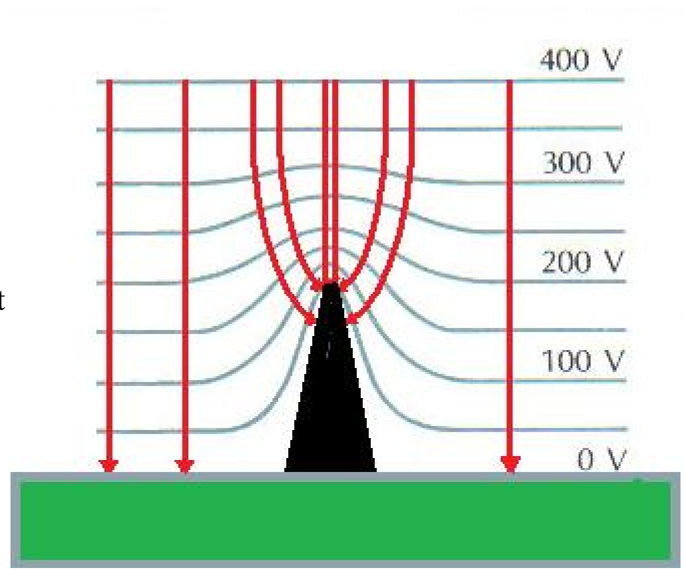


Figure 1 Distortion of field lines round a conducting object (grey - potential, red - field)

Now, we can all "feel" the gravitational force (just try jumping up and down) and we can easily detect magnetic fields with a compass needle. Indeed, these forces are very easily measured [1], [2]. The electric field, however, is more of a mystery and this is largely to do with the fact that it does not come indoors. This is a major obstacle to detection. An illustration is given in Figure 1:

Any conducting object at ground level will distort both potential and field lines of an electric field as shown. Houses, trees and people all have relatively good conductivity when compared to the surrounding air and therefore electric fields will not be present *inside* buildings at ground level.

It was taken as a challenge to measure this field and in doing so it was hoped that students would be made more aware of the vast topic of Atmospheric Physics.

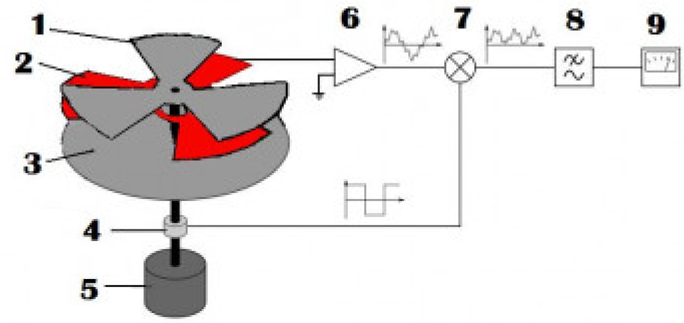
It may be worthwhile visiting "University of Reading METFiDAS weather observations". On this web page, note that PG (potential gradient) denotes electric field.

Graphical data, listed under the heading "Atmospheric Electricity" at the bottom of the web page, shows the electric field values for the particular location of Reading, UK.

Figure 2 - Diagram of a typical Field Mill with electronic circuitry

Apparatus

A little background reading showed that a Field Mill was the most common arrangement for this field measurement and a typical layout is shown in Figure 2:



The key for Figure 2 is as follows:
1 - **Rotor blade** at earth potential, turned by the **motor** (item **5**)
2 - **Fixed plate** isolated from earth (this is also called the **sensor plate**)
3 - **Ground plate**, also held at earth potential
4 - **Tachometer** with three equally spaced black and white partitions for its optical switch
5 - **Motor** providing power to the **rotor blade** (item **1**)
6 - **Charge amplifier**
7 - **Mixing device** and in the present apparatus it is a **multiplier circuit** AD 633
8 - **Low pass filter**
9 - **Centre-zero meter**

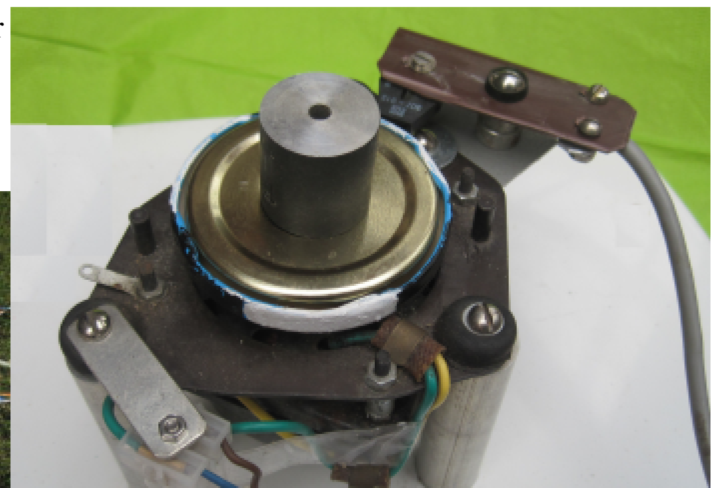


Figure 3 - Photograph showing the motor plus tachometer

In the present work, item **5** is a small motor with a disc attached to the spindle as shown in Figure 3:

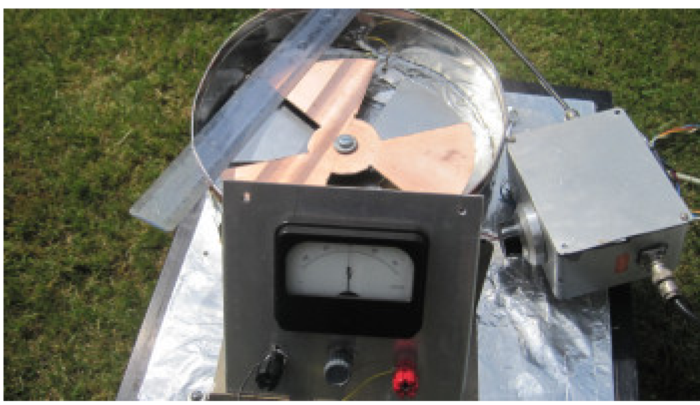


Figure 4 - Field Mill with separate charge amplifier (item 6) and centre-zero meter (item 9) resting on the case (ruler indicates the size of the apparatus)

Three black and three white stripes were painted on the rim so that the reflective optical-switch (RS Components Ltd, RS 307-913 or Optek OPB704W-Z supplied by Amazon) gave a square wave output signal.

The motor also turns the rotor blade (item **1**).

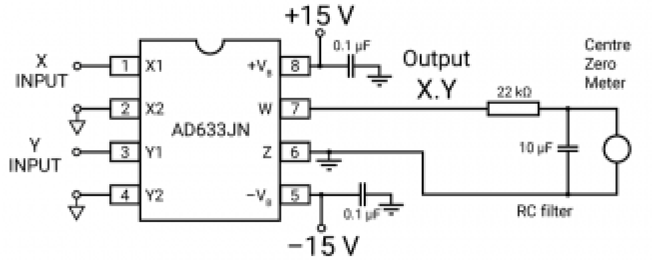
The ground plate (item **3)** is fabricated from a steel biscuit tin and the upper part of the spindle passes through.

The charge sensor plate (item **2**) is supported by this tin on insulated pillars and is alternately ***exposed to*** or ***shielded from*** the incident field by the rotor blade plate (item **1**).

The instrument/apparatus, positioned at gound level, is shown in Figure 4. Both the stationary and rotating blades are enclosed in a biscuit tin so allowing the instrument to be zeroed when the tin lid is placed on the tin. It also provided electrical shielding as extraneous noise from the motor was quite high.

Figure 5 - Multiplier circuit (item 7) for mixing the tacho and charge signals (X and Y)

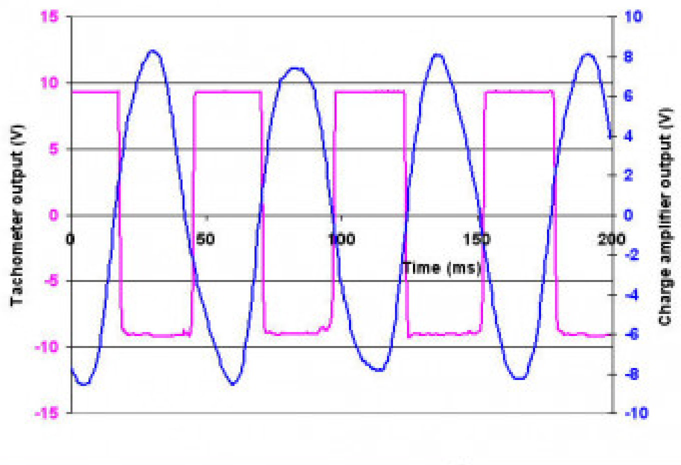
The charge amplifier, encased in a separate metallic box, rests on the case of the apparatus and is connected to the fixed plate (item **2)**. If the signal from this amplifier were to be rectified then only the magnitude of the field would be measured and whether the field was incoming or outgoing would not be determined. But, by using ***a mixer*** (item **7**). we have synchronous demodulation which gives the sign of the field and a significant noise reduction.

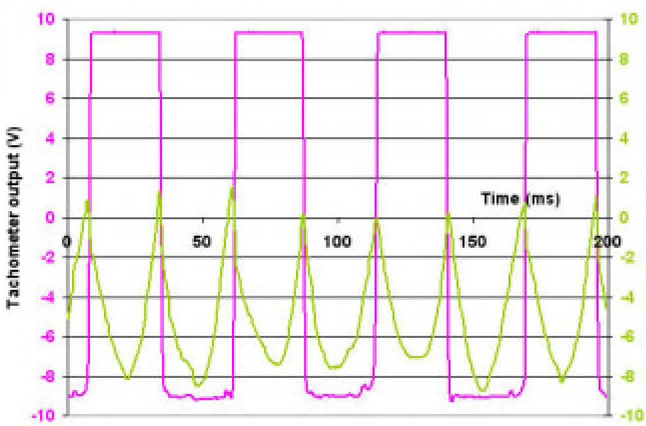


Basic multiplier connections

Commercial instruments are available for these measurements (e.g. Model 410 Scitech Instruments Ltd) and Figure 5 shows a low-cost alternative:

Figure 6 - Signals obtained when a charged PTFE rod is positioned over the Field Mill. (a) Signals from the tachometer (red) and the charge amplifier (blue)



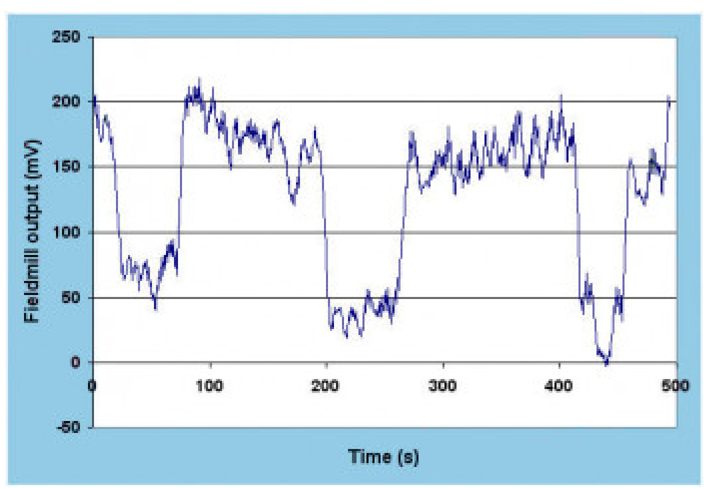


6(b) Signals from the tachometer (red) and the mixer (green)

In setting up the field mill one can place a charged object over the sensor plate (item 2) and observe the following signals. See Figure 6 (a), (b):

The output from the multiplier circuit is then passed through a low-pass filter and displayed on a centre-zero meter (item 9). The above readings (in Figure 6) were taken with a PicoScope 5242A oscilloscope and copied to Excel spreadsheets.

Preliminary results



After the setting up, we can be confident that the output voltage from the filtered signal is directly proportional to the earth's field and a typical, fine day, outdoor graph is given in Figure 7:

As a very approximate calibration (carried out at the meteorological department of Reading University) the output readings in mV could be converted directly into field readings in V/m. Thus, the field mill gives the earth's electric field as 120 (±20) Vm^-1 as the covered reading of approximately 50 mV is subtracted from the uncovered reading of 170 mV. Further measurements

were made with the field mill on 22 June 2017. A thunderstorm had been forecast so there was a possibility of variability in the earth's electric field.

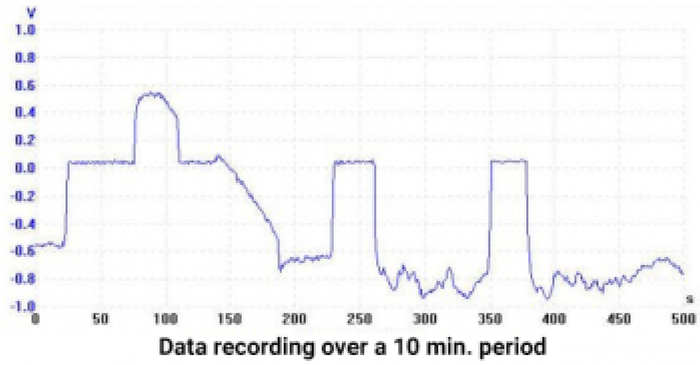


Figure 8 - Earth's electric field changes as a thunderstorm was approaching (rotor covered for periods 30–70, 107–140, 230–260 and 350–380 seconds).

The apparatus was placed in an open space at about 8:15 am and the trace (Figure 8) was obtained. At approximately 8:30 am both the meter and the trace were off-scale, indicating a large negative signal. Adjustment of the gain by a factor of 10x restored an on-scale signal and, for several periods a zero signal condition was tested by placing the tin lid over the rotor. The changes in the signal were quite rapid as Figure 8 shows:

In Figure 8 we see that the earth's electric field changes from negative to positive in about 30 seconds and then the positive signal changes to negative in about 100 seconds.

The instrument had to be moved indoors after 600s as rainfall had commenced. Thunder and lightning occurred shortly afterwards. The electric field is seen to vary between +600 V/m and –1 kV/m.

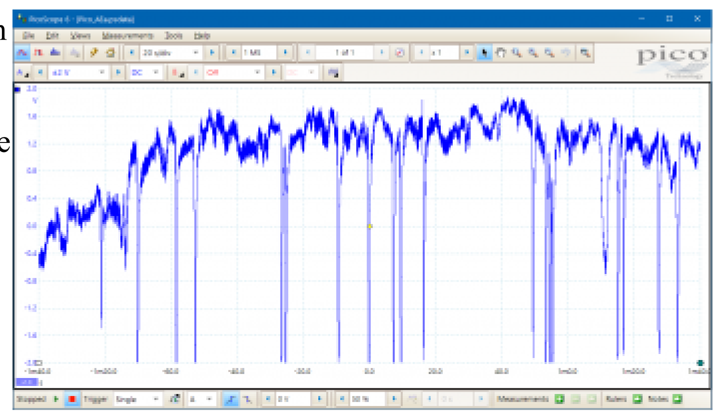


Figure 9 - Trace showing the atmospheric electric field on a fine day

The PicoScope 5242A is ideal for data logging as the time scale can be set as long as 5000 seconds per division. Figure 9 shows a typical fine weather trace for about 5 mins:

For the initial minute the rotating blade was covered with the tin lid and then it was uncovered for the rest of the time. The observed spikes were assumed to be spurious but further measurements need to be carried out to see if they are caused by an instrumental defect.

Conclusions

On a fair-weather day, the Earth's electric field was found to be close to 120 V/m but the accuracy for these preliminary results was at best ±20%. This agrees with the Schiller statement. The offset error of approximately 50 mV is likely to result from imperfect blade dimensions and/or the black and white tachometer divisions as these were hand-painted.

The variability of the Earth's electric field (Reading University - graphical data showing potential gradient) does pose a problem so it is advisable to carry out measurements on a fine day and then the field will be close to 120 V/m.

As a final point, the signal-to-noise performance of the apparatus is very low even with blade diameters close to 20 cm. If one could replace the simple mixer with a phase sensitive detector (PSD) then improvements would be possible. The PSD would greatly simplify the setting up procedure of the apparatus as both gain and phase of the charge signal could then be adjusted.